

# Gyrokinetic simulations of turbulence and flows in limiter tokamaks

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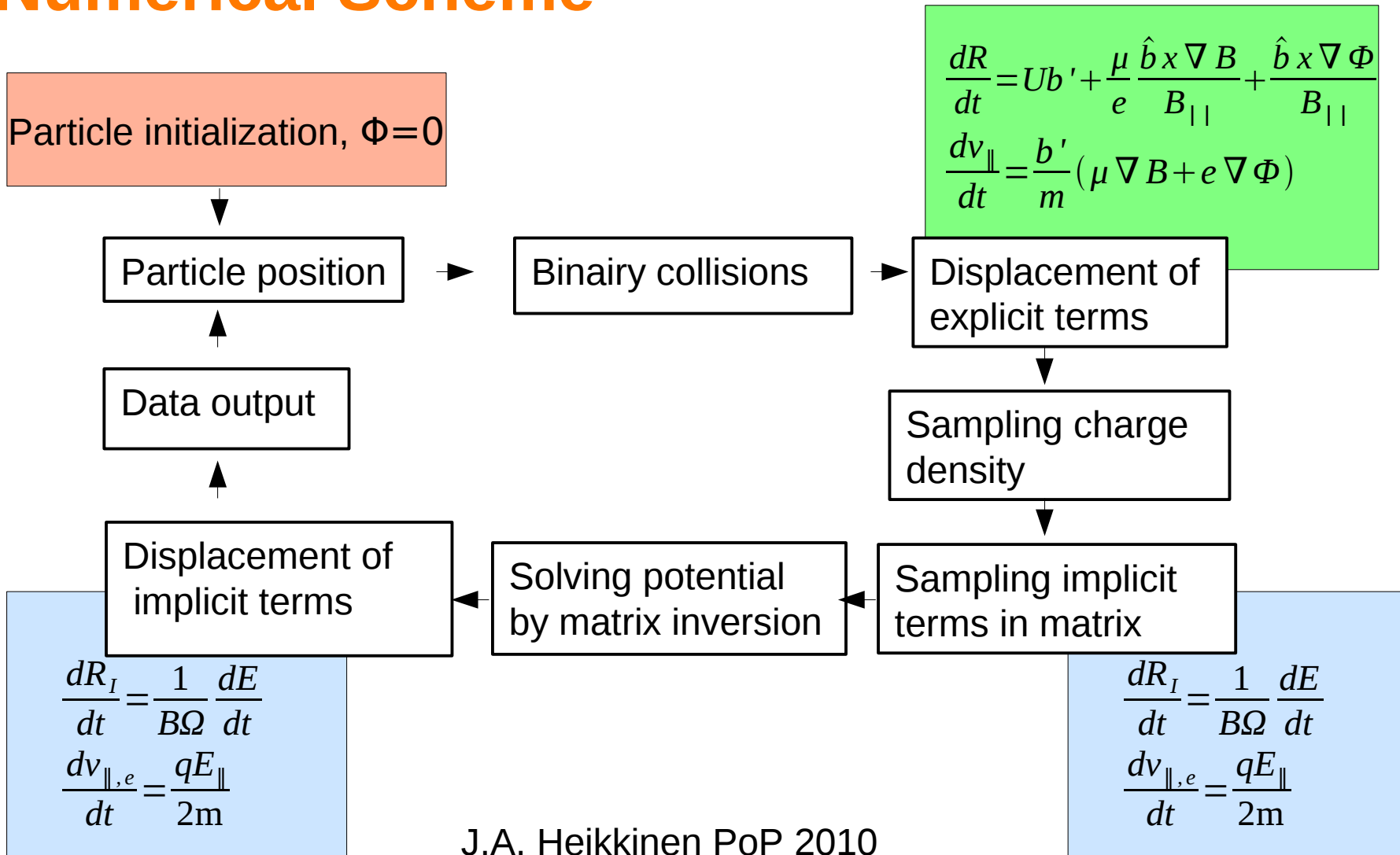
# Outline

- The computational tool ELMFIRE
- Benchmarks & Validations in the core
- Lmode & Hmode Textor simulations

# Elmfire code features

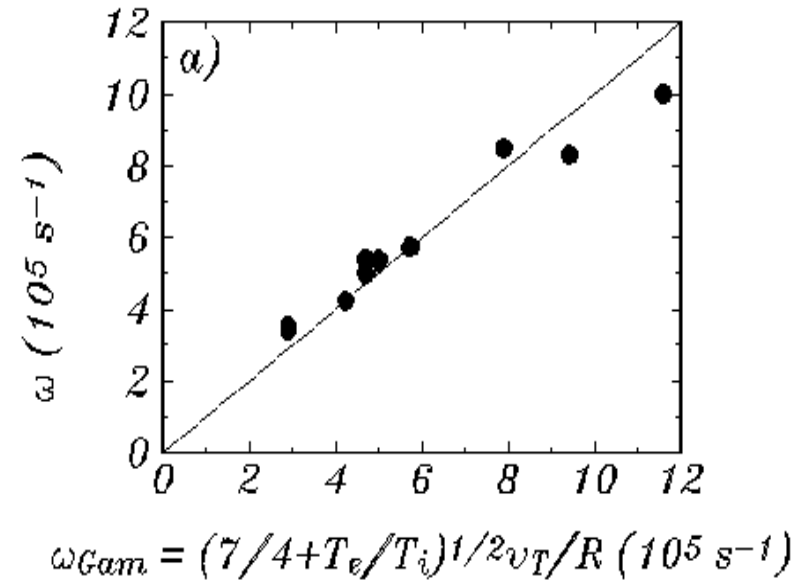
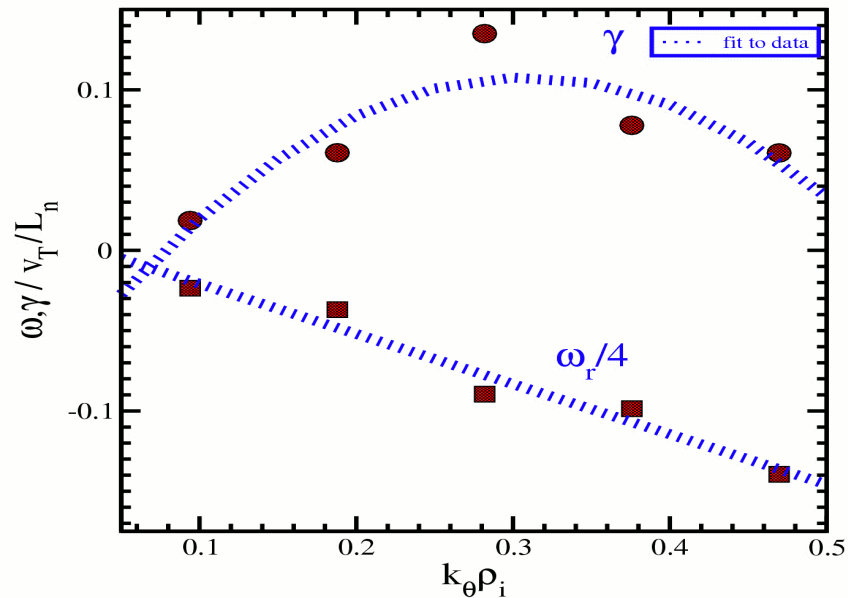
- Nonlinear gyrokinetic particle in cell code
- Global and Full  $f$
- Electrostatic
- Concentric circle magnetic field background
- Implicit solver for the polarization drift and the parallel electron acceleration
- modes  $k_{\theta} \rho_s < 1$  (TEM & ITG)
- Kinetic ions & electrons
- Impurities
- Binary collision model (e-e, e-i, i-i, e-l, l-l, l-i, ...)
- Simulates turbulence, zonal flows and mean ExB flows simultaneously

# Numerical Scheme



J.A. Heikkinen PoP 2010

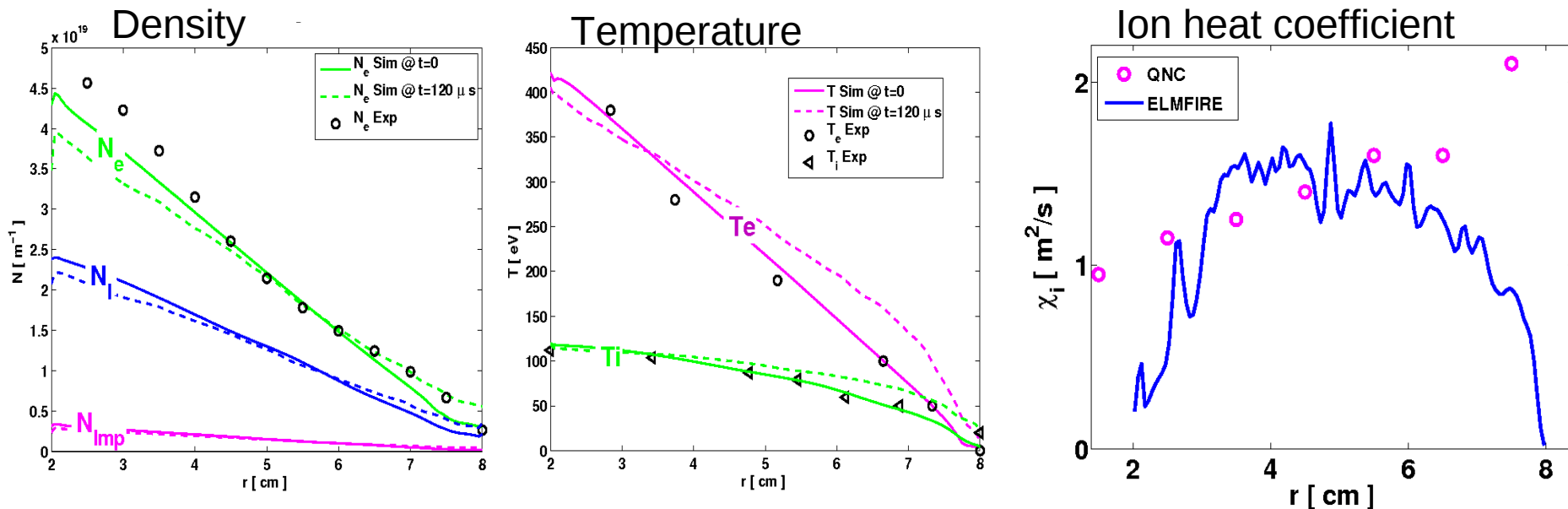
# Cyclone & GAM benchmark



J.A. Heikkinen et al. Journal of Computational. Physics 227, 5582 (2008)

# FT2 Code Validation: steady state profiles

$R0=55$  cm,  $a=8$ cm,  $I=18.9$  kA,  $\rho^*=1/80$ ,  $\nu^*=10-25$ ,  $Z_{eff}=3.5$  ( $O^2$  8+)  
Simulation domain=2-8cm, Grid=120rad/150pol/8tor,  $\Delta t=30$ ns,  $t=0.3$  ms



- Ohmic heating model by loop voltage, radiation& CX losses, Limiter model, recycling

# Reflectometry

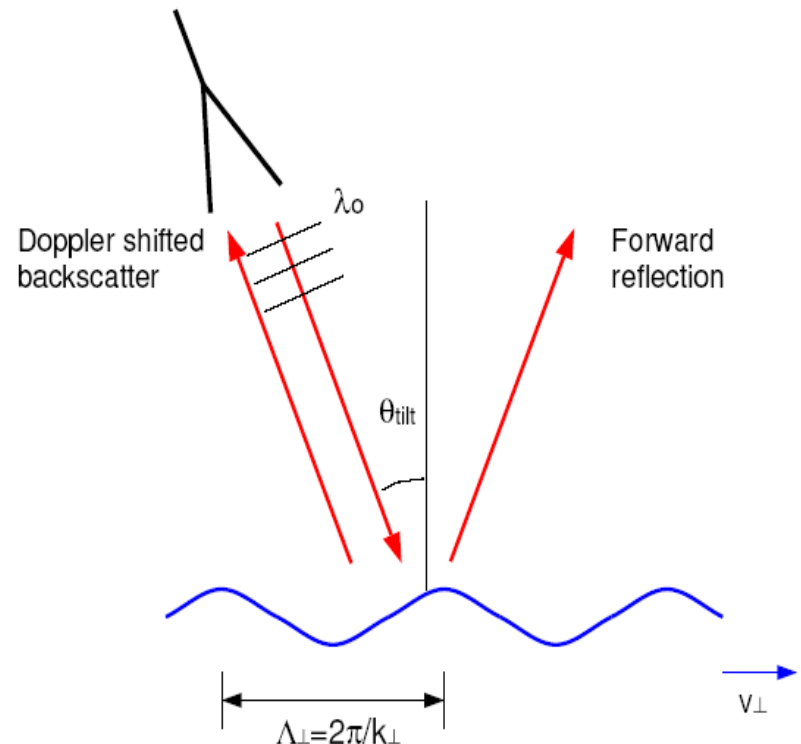
Reflectometry measures the poloidal velocity by evaluation of the rotational velocity from the frequency shift of microwave back scattered radiation

The output signal of a quadrature detector is given by

$$I(t) = \int w(r, \theta) \delta n(r, \theta, t) r dr d\theta$$

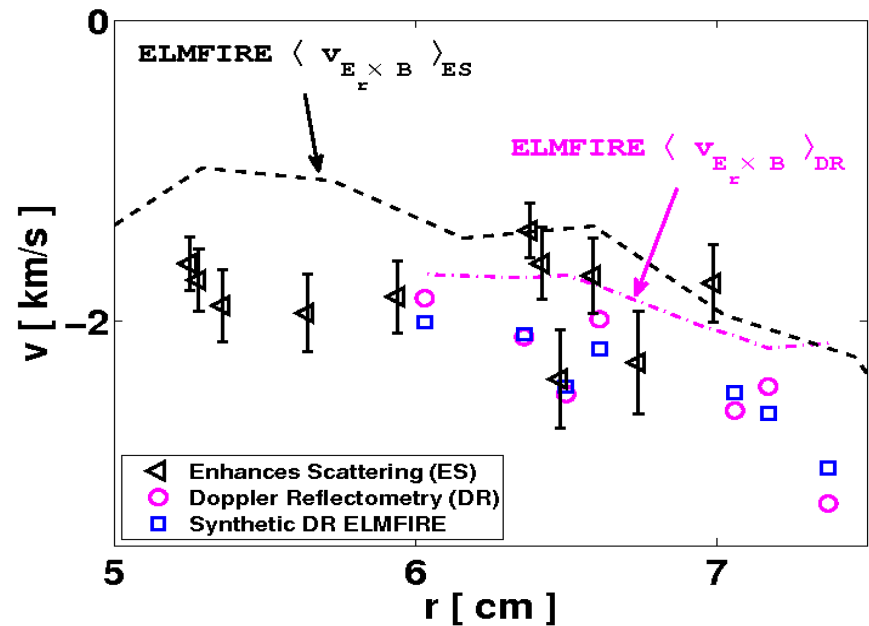
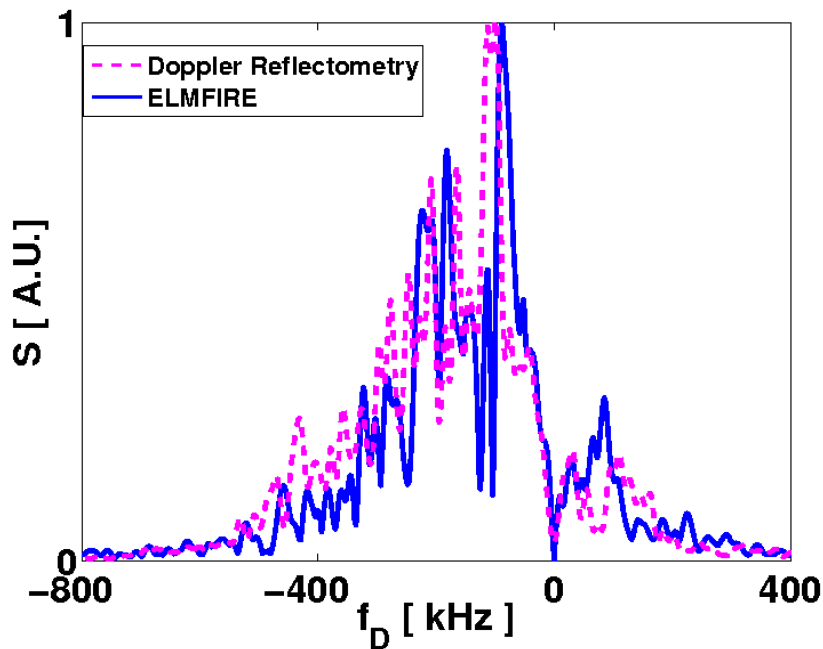
$W(r, \theta)$  = Weightingfunction calculated by beam tracing code

$\delta n(r, \theta, t)$  = Density fluctuations simulated by ELMFIRE code

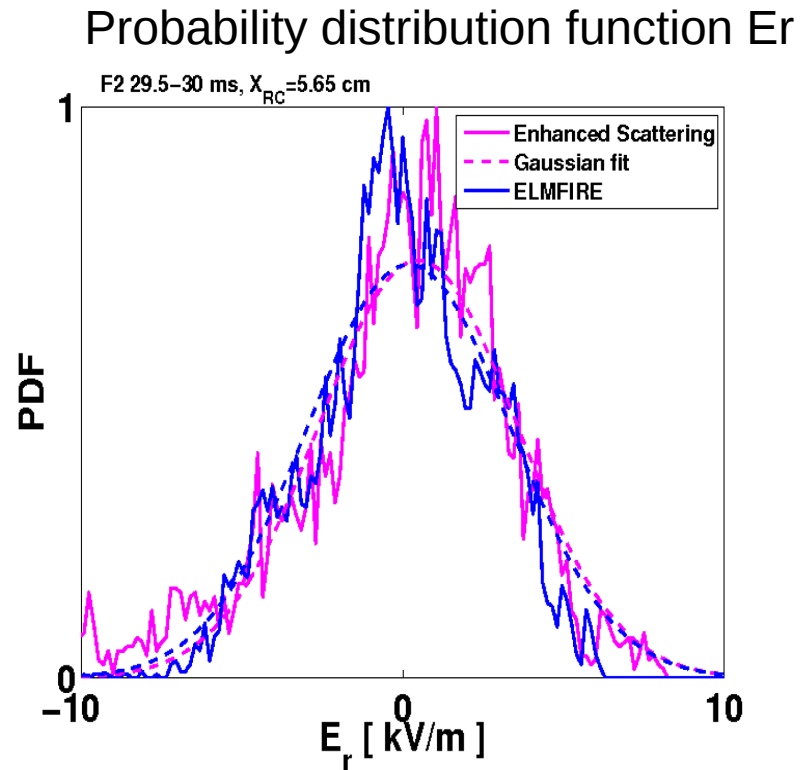
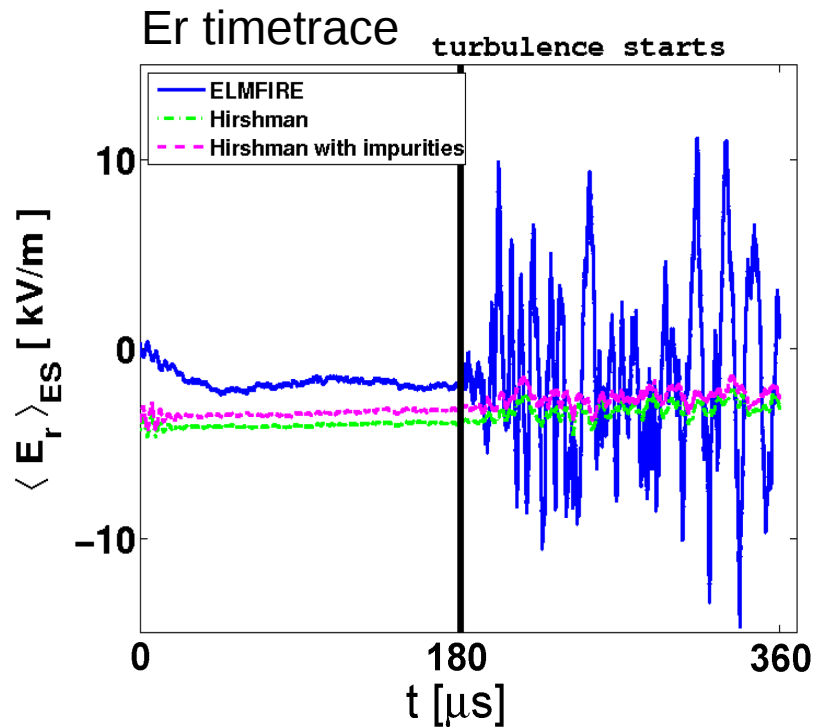


# FT2 Code validation: poloidal rotation

$$I(t) = \int w(r, \theta) \delta n(r, \theta, t) r dr d\theta$$



# FT2 Code Validation: Radial electric field

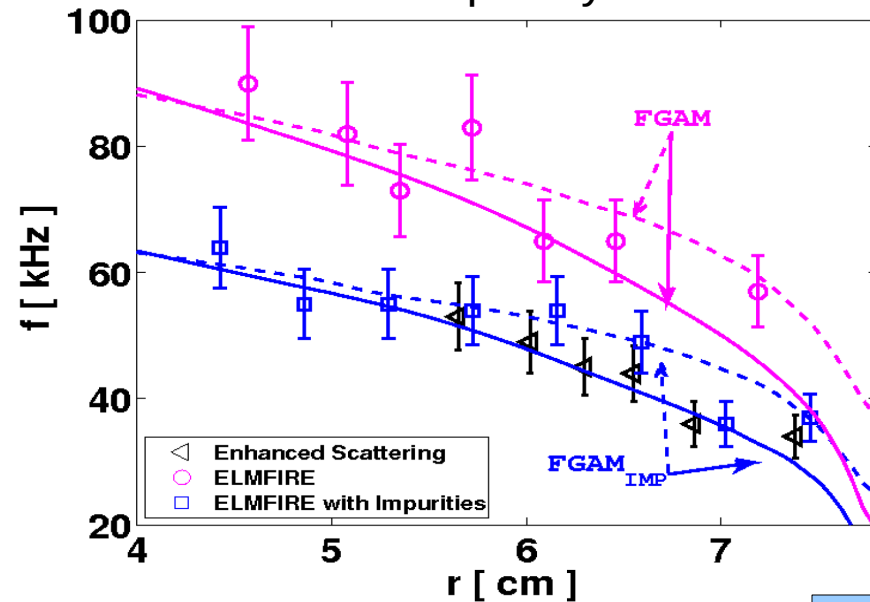


Bruce D Scott 2005 New J. Phys. 7 92

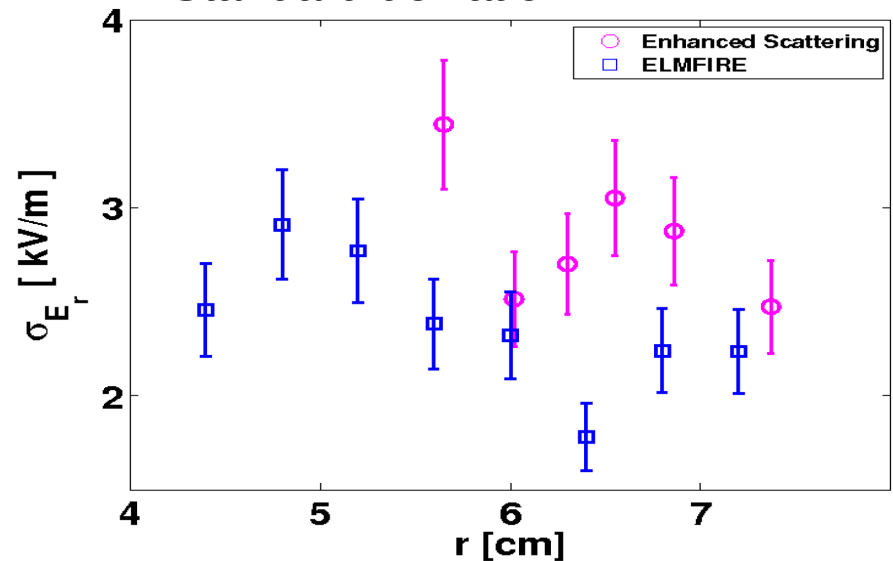
G D Conway et al 2005 Plasma Phys. Control. Fusion 47 1165

# FT2 Code Validation: Radial electric field

Dominant frequency



Standard deviation Er



$$\omega_{GAM} = \frac{v_{t,i}}{R} \sqrt{\frac{7}{4} + \frac{T_e}{T_i}}$$

$$\omega_{IMP} = \frac{7/4(n_I + n_Z) + A}{n_I m_I + n_Z m_Z} + \frac{23/8(n_I/m_I + n_Z/m_Z + B)}{7/4(n_I + n_Z) + A} q^2$$

Guo et al. PoP 17(2010)112510

# Textor Profiles L-mode versus H-mode

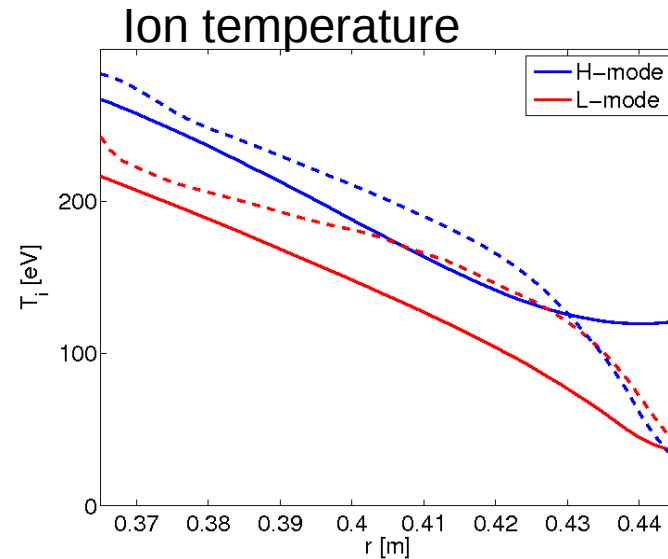
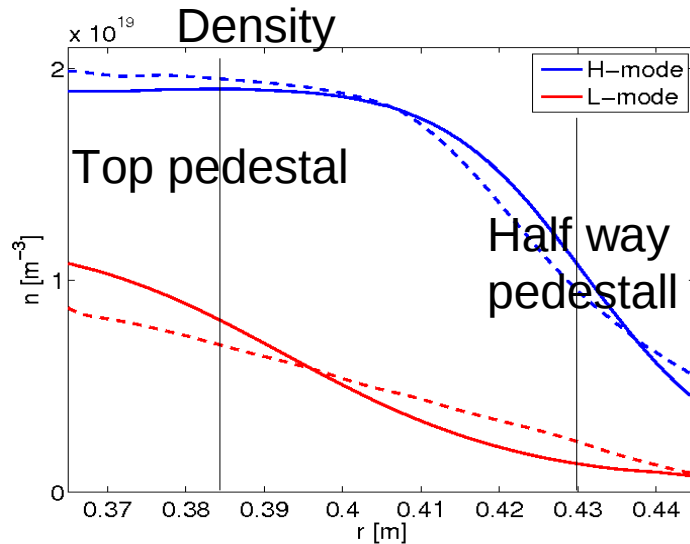
S.Soldatov et al. Plasma Phys. Contr. Fusion 52, 085001 (2010):

- The rotation shear and  $E_r$  were presented for limiter H&L-mode TEXTOR plasmas measured with probes and reflectometry.
- Lower level of turbulence were found for the H-mode silent stage in the inter ELM silent stage compared to L-mode.
- No significant difference was found for the radial profile of  $E_r$  between L-mode and H-mode.

G.D. Conway et al. PRL 106 (2011)

- Evidence is presented of the GAM-ZF-mean flow-turbulence interaction in Asdex Upgrade where the GAM flow dominates the turbulent L-mode but is suppressed in the quiescent H-mode

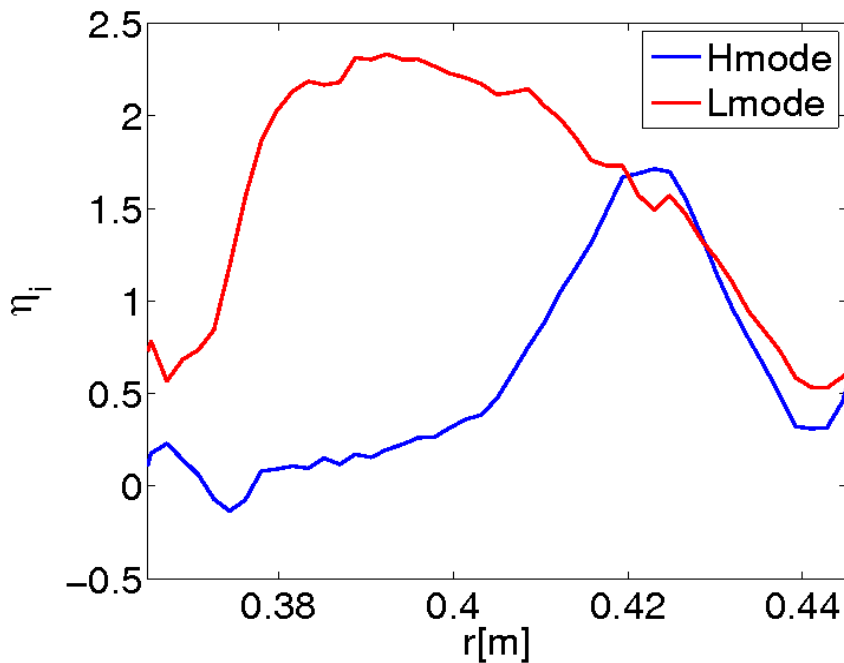
# Textor Profiles L-mode versus H-mode



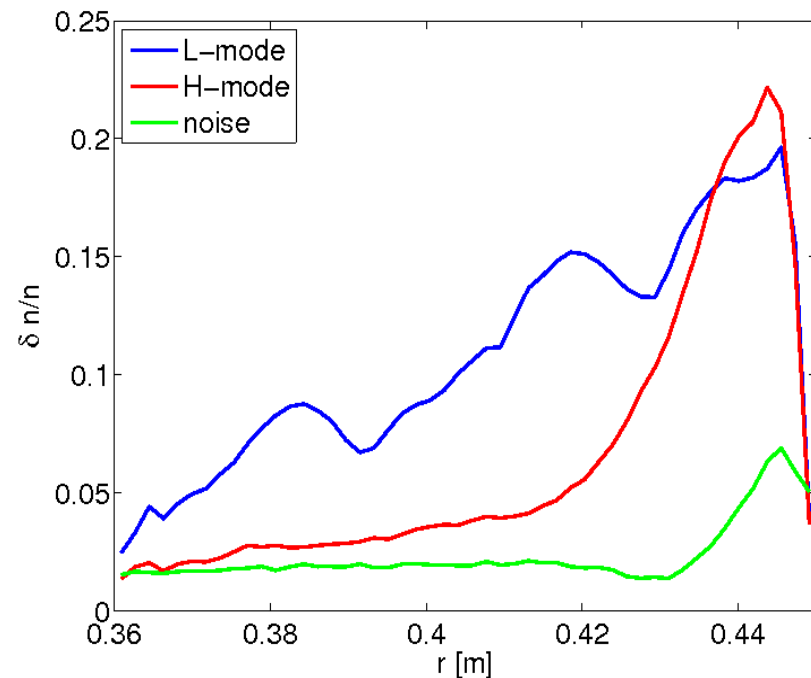
$R_0=175$  cm,  $a=46$ cm, simulation domain= 36-45 cm,  $\Delta t=100$ ns,  $t=1$  ms,  
Background heating & limiter model & recycling

# L-mode has stronger turbulence drive

Turbulence drive  $L_T/L_N$

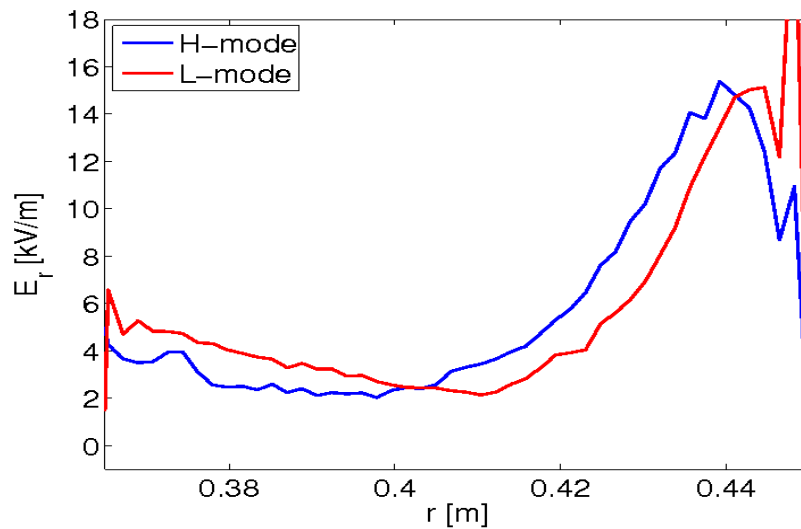


Ion density fluctuation level

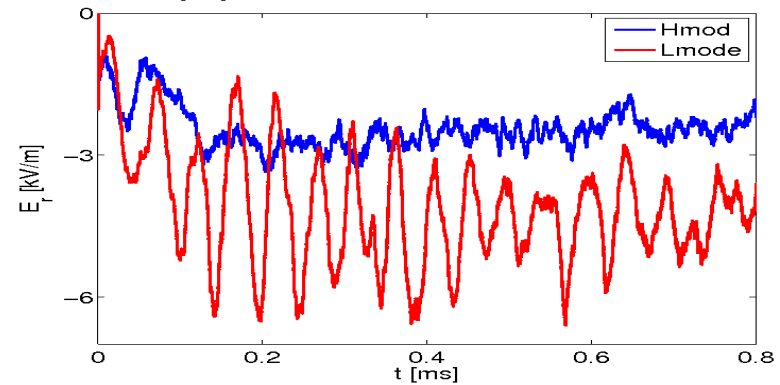


# Radial electric field

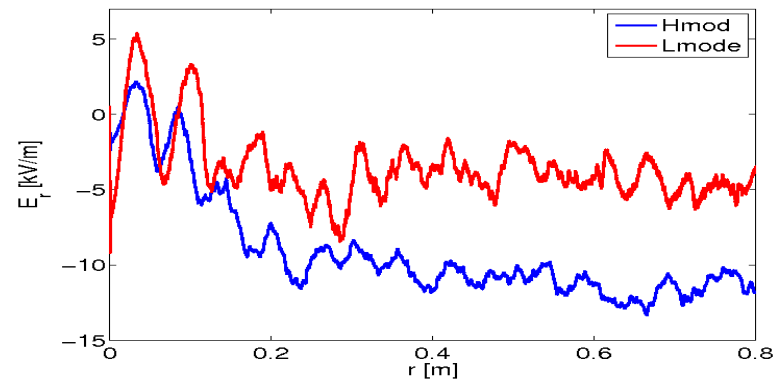
Radial profile



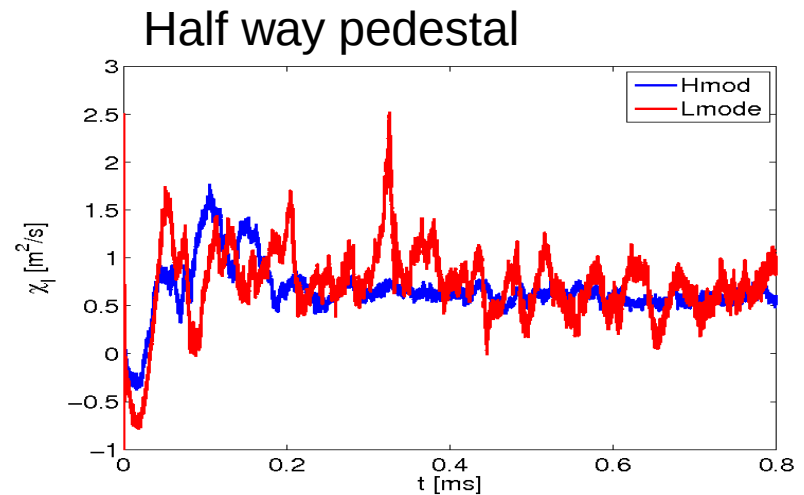
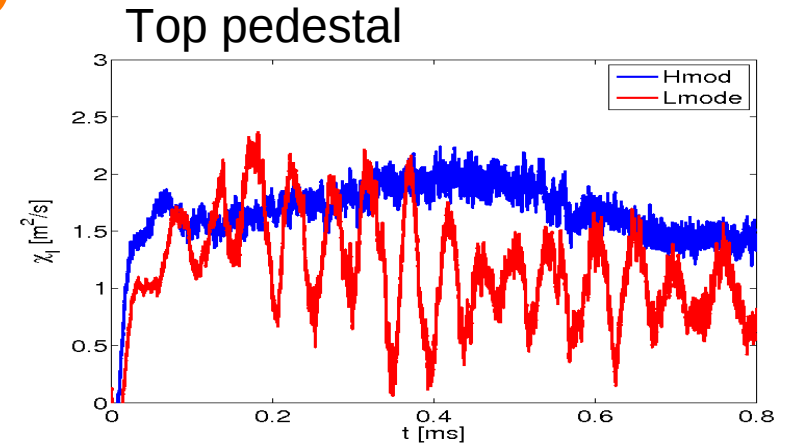
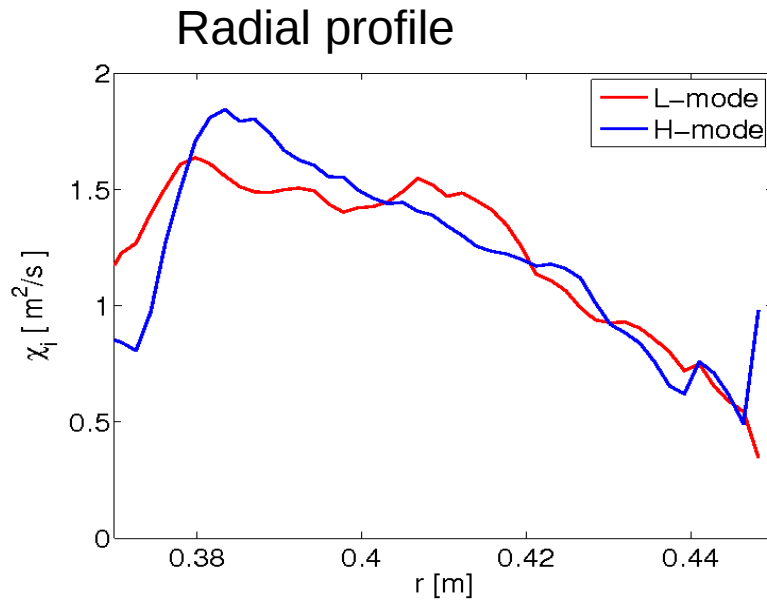
Top pedestal



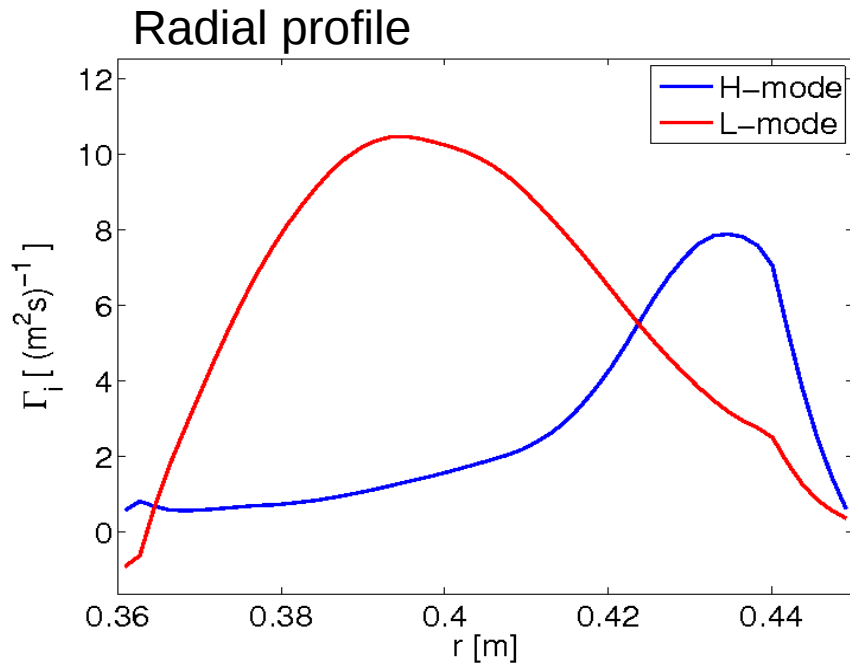
Half way pedestal



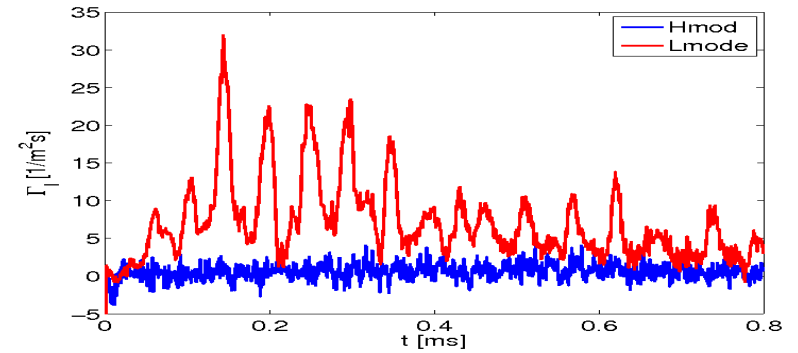
# Ion heat conductivity



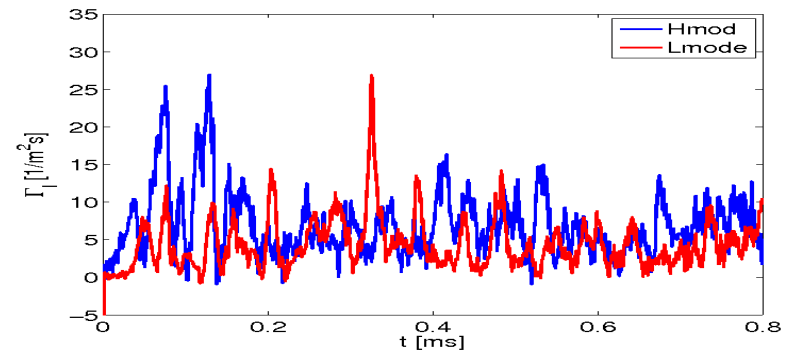
# Ion particle flux



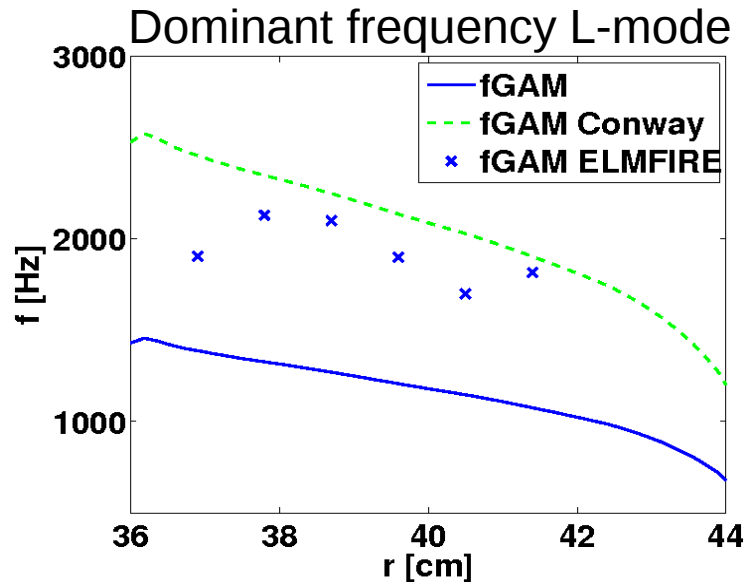
## Top pedestal



## Half way pedestal

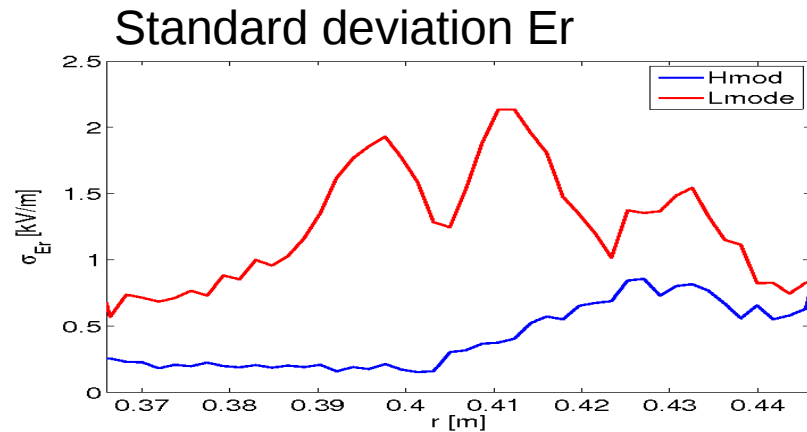
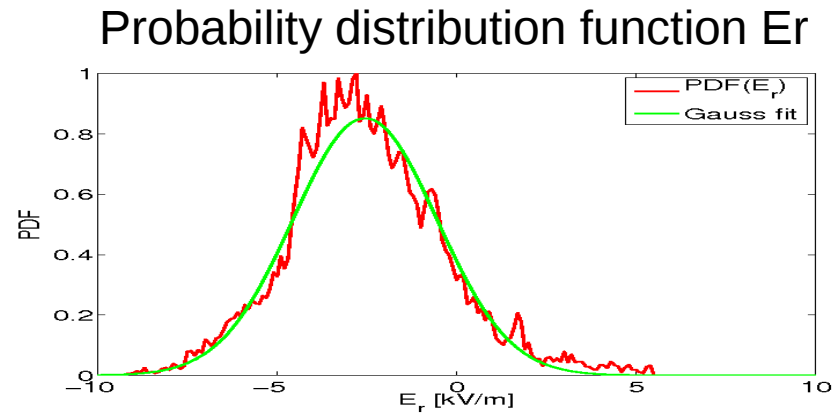


# Er Burstiness, Gaussian, GAM



$$\omega_{GAM} = \frac{v_{t,i}}{R} \sqrt{\frac{7}{4} + \frac{T_e}{T_i}}$$

$$\omega_{GAM,CONWAY} = \frac{4\pi((1+\kappa)^{-1}-0.3)}{\sqrt{1+7/4}} \frac{v_{t,i}}{R} \sqrt{\frac{7}{4} + \frac{T_e}{T_i}}$$



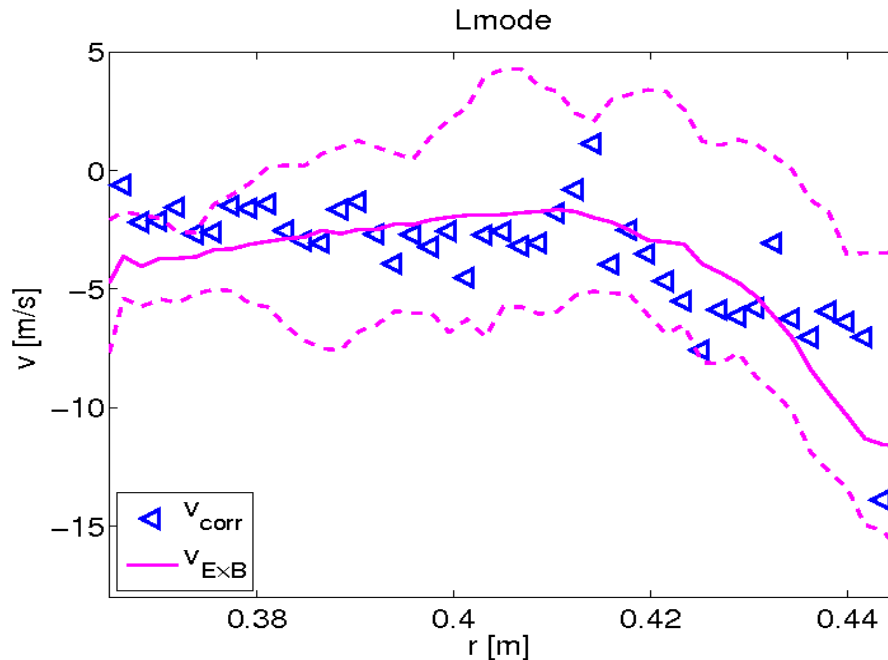
# Conclusion

As measured in Textor (Soldatov et al.) a lower turbulence level is found for the H-mode compared to L-mode and no significant difference was found for the radial profile of  $E_r$  between L-mode and H-mode.

A reduction of GAM activity is observed in H-mode compared to L-mode both at the pedestal top as well as half way the pedestal.

The  $E_r$  oscillations are Gaussian distributed illustrating the stochastic nature of the source. The correlation between the turbulence drive and the GAM Amplitude suggests that the GAM is turbulence driven.

# V<sub>ExB</sub> much larger than v<sub>phase</sub>



$$v_{Corr} = \frac{l_{corr}}{t_{corr}} = v_{ExB} + v_{Phase}$$

$$v_{ExB} \gg v_{Phase}$$